Report for 2003ME19B: Defining 'natural' reference conditions and indicators to assess cumulative impacts of shoreline development on lakes in Maine

- Conference Proceedings:
    - Ness, K., K.E. Webster, R. Bouchard. 2005. What are the effects of shoreline development on lakes in Maine? Oral presentation at the Maine Water Conference, March 2005, Augusta.
    - Ness, K., K.E. Webster, R. Bouchard. 2005. What are the effects of shoreline development on lakes in Maine? Oral presentation at the 7th Annual Association of Graduate Students Research Exposition, April 2005, Augusta.
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    - Ness, K., K.E. Webster, R. Bouchard. 2004. Assessing the effects of shoreline development on lakes in Maine. Poster presentation at the Maine Water Conference, April 2004, Augusta, ME.

Report Follows

Basic Information:

Title:	Defining 'natural' reference conditions and indicators to assess cumulative impacts of shoreline development on lakes in Maine
Project Number:	2003ME19B
Start Date:	01 April 2003
End Date:	31 March 2005
Research Category:	Biological Sciences, Water Quality
Focus Category:	Ecology, nonpoint pollution, recreation, surface water, management and planning, water quality
Descriptors:	Biomonitoring, bioindicators, aquatic plants, lakes, shore protection
Lead Institute:	University of Maine
Principal Investigators:	Katherine E. Webster, Roy Bouchard

Problem and Research Objectives:

Lake ecosystems are currently at risk from increases in shoreline development. Lakes attract residential development (Walsh et al. 2003), placing lakefront property in increasingly high demand for residential construction of vacation and/or permanent homes around lakes. Although Maine is largely rural, many of the state's more than 5,000 larger lakes are at risk from shoreline development. In 1971, the State of Maine Department of Environmental Protection instituted protective shoreline regulations for lake riparian zones. The regulations under this Act control development actions within 250 feet of the high-water mark for ponds greater than 10 acres in size. Development restrictions include: 100 ft setbacks for structures, driveways, and roads, maximum amounts of vegetation that can be removed from a shoreline property, and rules for new septic system installations (Kent 1998). The goals of the Shoreland Zoning Act include prevention and improvements in water pollution, conservation of aesthetically pleasing areas, protection of wetlands, conservation of shoreline habitats, protection of wildlife habitats, and control of recreational activities.

Shoreline development can influence lake ecosystems through two general pathways. Through removal of riparian vegetation and tidying of nearshore areas, people decrease the amount of coarse woody debris (CWD) like trees and branches that provide important structural habitat for fishes and other organisms in the littoral zone. Construction and use of docks and other structures, as well as boating, and other recreation activities associated with them, mechanically disrupt littoral biota such as aquatic plants that provide critical habitat for other organisms. As a result, a simplification of littoral habitats is common in highly-developed lakes (Christensen et al. 1996; Engel and Pederson 1998; Radomski and Goeman 2000; Schindler et al. 2000; Jennings and Emmons 2001). In addition, construction of impervious structures or roads, fertilizer applications to lawns, destruction of riparian buffers, and leaky septic systems in riparian areas have potential to increase nutrient loading to lakes (Jennings et al. 1996; Engel and Pederson 1998; Dillon et al. 1994). If the capacity of the littoral zone to assimilate these nutrients is exceeded, lake trophic status is likely to degrade. In addition to these more 'indirect' pathways, shoreline development can directly affect littoral communities through mechanical disruption and possibly through increasing the probability of invasion by competitive exotic species. The overall impact of these pathways on the integrity of the lake ecosystem and on the resilience of lakes to other stressors like invasive species, eutrophication or climate change is unknown, but is key to effective management and protection.

Our overarching objective is to determine the effects of shoreline development on the habitat complexity of littoral zones in small headwater lakes in Maine. We define habitat complexity in terms of the physical structure provided by macrophytes and coarse woody debris. Macrophytes stabilize littoral sediments, act as a nutrient source upon decay, and provide habitat and food resources for littoral macroinvertebrate and fish species (Voights 1976; Crowder and Cooper 1982). Similarly, coarse woody debris serves as a habitat for macroinvertebrates and a place of colonization for algae which littoral fauna can used for nutrition (Harmon et al. 1986, Nilsen and Larimore 1973; McLachlan 1970; Anderson et al. 1978; Beckett et al. 1992).

Our specific research objectives are to:

1. *Define a 'natural' template that predicts structural complexity based on physical attributes in the absence of human activities*. Littoral zones are naturally quite heterogeneous in a range of physical factors such as slope, fetch, and substrate composition. Often the effects of shoreline development on littoral habitat have been determined without considering the range of possible physical conditions. By defining the natural template we can establish expectations for habitat structural complexity needed to quantify the effects of human activities.
2. *Determine how shoreline development influences habitat complexity.* Using expectations from objective 1, we have a more sensitive method for detecting the influence of shoreline development on habitat structure. We will then test whether indicators of response to structural complexity, namely macrophyte species composition and macroinvertebrate community structure, are sensitive to any observed changes in structural complexity. As part of this objective we will also determine whether structures constructed in accordance with Maine Shoreland Zoning Regulations provide better protection to littoral habitats.

Methodology:

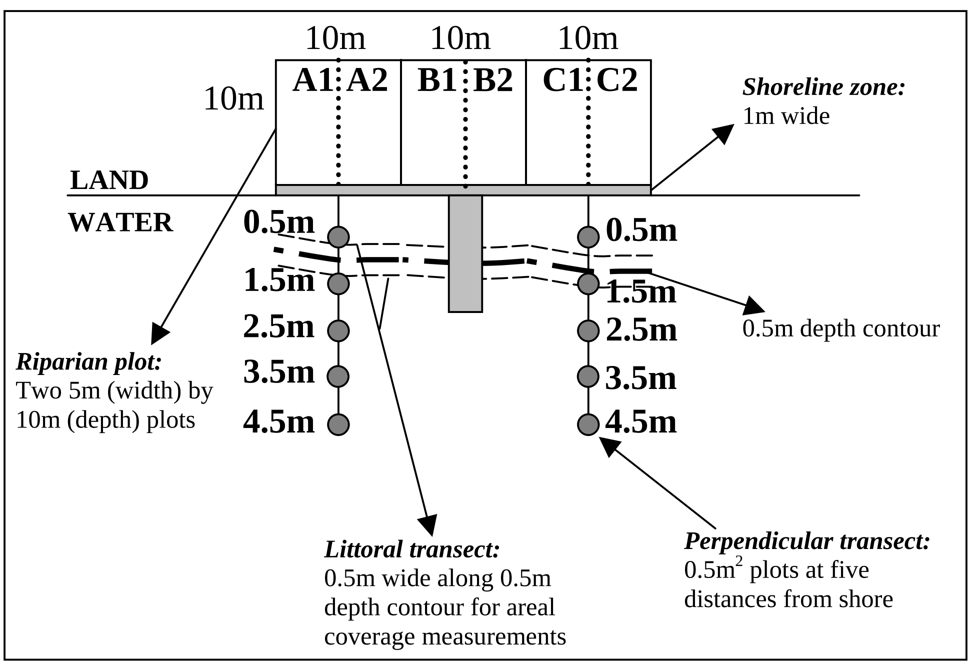
Study Lakes

We selected 11 study lakes located within a similar geologic setting in Hancock and Penobscot counties in eastern Maine. To reduce inherent variability, the lakes have similar hydrology (headwater) and surface area (20-200 hectares). In addition, the lakes were chosen to reflect differences in the extent of residential shoreline development around the perimeter. Six of the 11 lakes had little or no shoreline development along the shoreline (1 to 3 cottages) and were characterized as "undeveloped" lakes. "Developed" lakes had moderate to heavy amounts of development along half or more of the shoreline. Lakes were sampled during July and August of 2003 and 2004, with three sampled only in 2003, three only in 2004, and five sampled both summers (Table 1).

Table 1: Characteristics of lakes sampled during summer 2003 and 2004 sampling seasons. The MIDAS (Maine Information Display Analysis System) number is a unique identifier for each lake in the state of Maine.

Lake name	*Year(s) sampled*	*MIDAS*	*County location*	*Surface area (ha)*	*Max. depth (m)*	*Mean depth (m)*
Undeveloped						
Burnt Pond	2003, 2004	4354	Hancock	28.3	7.6	3.4
Fitts Pond	2003	4268	Penobscot	42.9	18.0	10.4
Green Lake #2	2003, 2004	4790	Hancock	25.9	3.7	2.7
Halfmile Pond	2003, 2004	4496	Hancock	44.1	18.6	7.6
Horseshoe Lake	2003, 2004	4788	Hancock	81.7	6.1	3.7
Upper Sabao Lake	2004	4522	Hancock	196.7	12.5	4.6
Developed						
Georges Pond	2004	4406	Hancock	153.8	13.7	4.9
Giles Pond	2003	4548	Hancock	25.9	2.7	1.8
Heart Pond	2004	4338	Hancock	29.5	21.0	9.8
Jacob Buck Pond	2003, 2004	4322	Hancock	76.9	15.8	6.7
Williams Pond	2003, 2004	5538	Hancock	45.3	15.2	7.3

Figure 1: Site design used during the 2003 and 2004 sampling seasons. Measurements were taken in subsite B at deliberately chosen developed sites only. Macrophytes were not assessed at 1.5 or 3.5 m along the perpendicular transect in 2003.



Study Design

In order to assess both the natural template and the effects of shoreline development, we employed two strategies to select sampling sites. On undeveloped lakes all 18 sites (or 8 sites for lakes sampled only in 2003) were randomly chosen to avoid bias inherent when deliberately choosing sites. These randomly selected sites were selected within equi-angular 'slices' to allow us to characterize the entire perimeter of the lake. On developed lakes we sampled 8 random sites, selected as described above, and 10 deliberately chosen sites. The deliberately chosen sites target development that conformed (5 per lake) and did not conform (5 per lake) to Maine Shoreland Zoning Regulations based on the amount of shoreline and riparian vegetation and the setback distance of the structure from the lakeshore. The 'random' sites allow assessment of lake-level effects of shoreline development while the 'developed' sites reflect more site-specific effects.

At randomly chosen sites in both undeveloped and developed lakes, we collected data at two subsites (A and C) to capture heterogeneity at the site level (Fig. 1). At deliberately chosen developed sites, data were also collected at subsite B, that was centered on the residence or the lake access for the property (i.e. docks or paths). For purposes of this report data from A and C are averaged for all analyses. Littoral variables were assessed along the 10 m transect at the 0.5 m depth contour parallel to shore and within $0.5m^2$ circular plots located every 1m from the shore to 4.5m. Shoreline variables were measured within the 1m shoreline zone which extended from the water's edge or the normal high water mark (if the lake level was low) to 1m inland. Riparian variables were measured within a 10m by 10m plot behind the shoreline transect.

Table 2: Habitat and biological variables measured during 2003 and 2004. Rows indicate the set of variables while columns show the location of data collection (see Fig. 1).

Variables	***Littoral Transect (0.5m depth)***	***Perpendicular Transect***	***Riparian Plot***	***Shoreline Zone***
Physical template	Substrate type[a] Fetch Aspect	Substrate type[a] Littoral slope	Slope Aspect	Substrate type[a]
Habitat complexity	Macrophyte structural type[b] ; Coarse woody debris	Macrophyte structural type[b]; Coarse woody debris	Vegetation structure[c] and type[d]	Vegetation structure[c] and type[d]; Overhanging vegetation
Response Variables	Macroinvertebrate community; Substrate embeddedness[e]	Macrophyte species; Substrate embeddedness[e]		
Human activity	Evidence of human use (boats, docks, etc)		Impervious surface; Type and footprint of structure; Pre- or post- legislation	

[a]Substrate type = sand, cobble, boulder and bedrock; [b]Macrophyte structure = submerged, emergent, floating leaf; [c]Vegetation structure = tree height category, shrub, etc.; [d]Vegetation type = deciduous, coniferous, or mixed; [e]Embeddedness = the relative degree to which the sediments are covered with fine silt

Data Collection:

Data collection in the littoral and riparian zone focused on four sets of variables defining: (1) the physical template; (2) structural complexity; (3) biological and physical response variables; and (4) the extent of human activities (Table 2).

Littoral and riparian physical variables. Percent substrate composition was based on size in the following categories: bedrock (larger than a car), boulder (basketball to car size), cobble/gravel (ladybug to basketball size), sand (smaller than a ladybug and gritty in texture), and fine sediments (smaller than a ladybug but not gritty in texture). Slope of the riparian plot was measured using a clinometer. Littoral slope was calculated using depth measurements taken at meter intervals along the perpendicular transect. Aspect was obtained either onsite with a compass or derived from a Digital Elevation Model in ArcGIS. Fetch was calculated using a fetch calculation script in ArcGIS.

Littoral and riparian habitat complexity variables. We estimated littoral and riparian habitat complexity based on macrophyte structural type, coarse woody debris, and riparian vegetation structure. Macrophyte structural type included: emergent, submergent, floating leaf, ground cover, and freely floating. The percent coverage of emergent, submergent and floating leaf plants was combined into a variable reflecting macrophyte structure. All coarse woody debris that was greater than 5cm but less than 10cm in diameter was tallied along the 10 m littoral transect. Coarse woody debris 10cm and larger in diameter was counted and assessed for the degree of decay, amount of branching, elevation above the substrate, orientation to the transect, and length. The percent coverage of coarse woody debris greater than 1cm in diameter was assessed along the perpendicular transect. Within the shoreline and riparian zones, we determined the percent coverage of different strata of vegetation based on the following classification: tree stratum >5m high; high shrub stratum 1.5-5m; low shrub stratum 0.1-1.5 m; and ground stratum <0.1m. The dominant type of vegetation (deciduous, coniferous, or mixed) was determined for the tree and high shrub strata. In the shoreline zone we also measured the percent of the shoreline covered by overhanging trees and shrubs.

Response variables. The response variables included macroinvertebrate community composition, macrophyte species assemblage, and substrate embeddedness. Macroinvertebrates were sampled at 8 sites on undeveloped lakes and 11 sites on developed lakes using activity traps constructed from two 1-L soda bottles (modified from Muscha et al. 2001 and Hyvönen and Nummi 2000). Two traps were supported horizontally approximately 20cm from the substrate in the water column by a PVC support column. Duplicate sets of traps were set at subsites A and B at each site along the 0.5 m depth contour. A yellow-green glow stick placed in each soda bottle served as an attractant to invertebrates. This trapping method is selective but was most efficient for our study because of the short time required for colonization (Muscha et al. 2001; Hyvönen and Nummi 2000). Macroinvertebrates were sorted, counted, and identified to order in the laboratory. In addition to using macrophyte form as part of a measure of habitat structure (see above), we also used measures of species assemblages as a response variable. Macrophyte species were identified in $0.5m^2$ plots at meter intervals along the perpendicular transect at each site. Following Jennings et al. (2003), we included measures of substrate embeddedness, which was classified depending on coverage of boulder and cobble/gravel substrates by sand or fine sediments. The percent coverage categories included: <5%, 5-25%, 25-50%, 50-75%, and 75-100% (Platts et al. 1983).

Human activity. In order to assess the effects of shoreline development on riparian and littoral habitats, we measured the human activity at developed sites. Measures included the set back distance of the structure from the shoreline, the size and type of structure, whether it conformed to regulations or not, and the presence of boats and docks. At the whole lake scale, the number of residences was recorded for each lake.

Data Analysis

We are using a multivariate technique, nonmetric multidimensional scaling (NMS), to define the ‘natural’ template using data on physical variables collected at sites in undeveloped lakes. NMS is an appropriate technique for our data set because the model does not require normality and variables measured at different scales can be included in the same analysis. The physical variables included in the NMS were the percentages of bedrock, boulder, cobble/gravel, sand and fine sediments along the littoral transects and littoral slope, riparian slope, and fetch. We ran the NMS model using PC-ORD 4.36 (McCune and Mefford 1999) in autopilot mode using the Sorensen (Bray-Curtis) distance measure, random starting coordinates, and 40 runs with the real data to find the number of dimensions to describe the data set. After determining the appropriate number of dimensions, the model was rerun using starting coordinates from the initial model and one run with the real data for the final model. The percent coverage of littoral macrophyte types was then overlain to explore relationships with the physical variables. While the results are not included in this report, the output from the NMS will be used to determine combinations of physical variables that best explain distributions of coarse woody debris and macrophyte form, variables that we are using to define structural complexity.

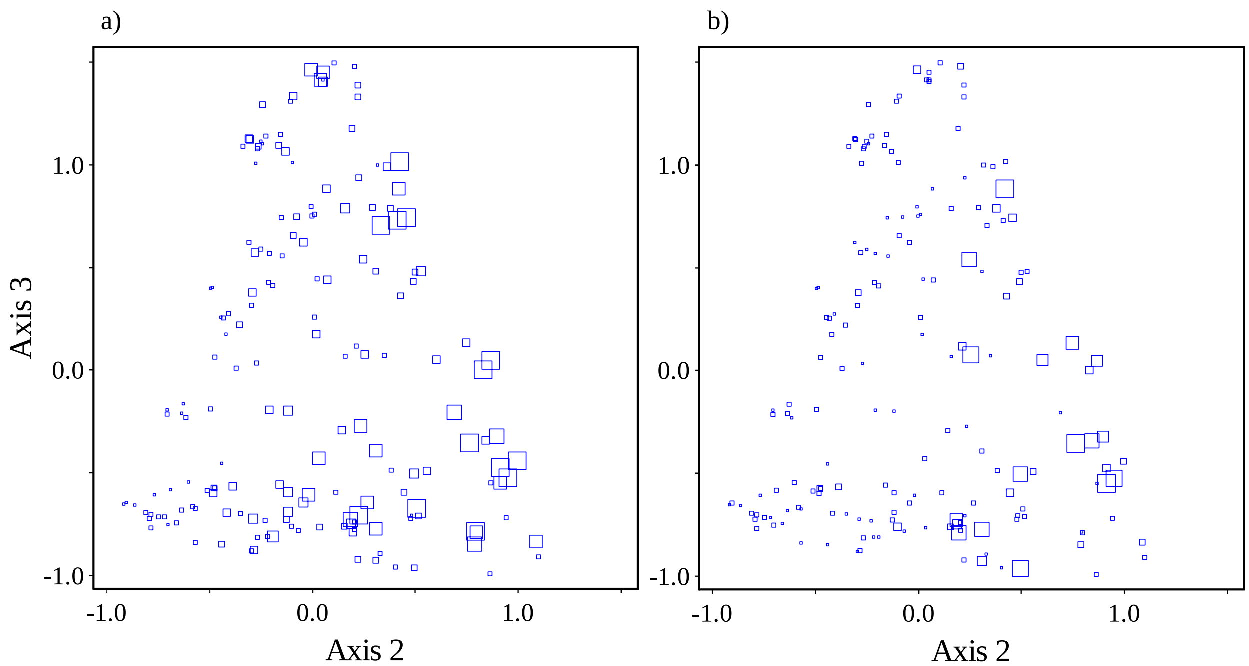
We then examined differences in riparian and littoral structural features among undeveloped sites on undeveloped lakes, random sites on developed lakes, and developed sites on developed lakes. Because the data were not normally distributed, randomization tests were performed to determine differences among site types, lakes, and sites. The data were shuffled and Monte Carlo analyses were performed using PopTools in Microsoft Excel (Hood 2005). The Monte Carlo analysis involved 1000 iterations for each variable and used an F statistic to determine the p value. We focus here on two comparisons: undeveloped vs. random sites and random vs. developed sites.

Principal Findings:

Natural Template

The NMS model described patterns in the physical variables that comprise the natural template for the littoral zone. For the final model, the second and third axes accounted for 14% and 61% of the variance, respectively, among undeveloped sites. Undeveloped sites were grouped primarily by substrate type and lake fetch, while riparian and littoral slope seemed less important. The overlay of macrophytes on the NMS axes suggests that percent coverage of macrophytes (emergent + submergent + freely floating) was related to percent coverage values of fine sediments (Fig. 2). Additionally, this group of macrophytes was generally not found in areas with high values for lake fetch. Floating leaf and ground cover macrophytes were more evenly distributed across substrate types and did not show strong relationships with any particular substrate type. The results support our hypothesis that physical features influence habitat complexity and need to be accounted for when evaluating littoral zone structure.

Figure 2: Results of the NMS analysis of physical variables measured at undeveloped sites on undeveloped lakes. Higher values off (a) % fine sediment and (b) % emergent + submergent + freely-floating macrophytes are shown by the size of the symbol on the graphs below. Macrophyte data are shown as an overlay on the NMS plots.



Effects of Shoreline Development on Habitat Structure

For this analysis we compared percent coverage of our key riparian and littoral structural variables among *undeveloped* sites (on undeveloped lakes), *random* sites (on developed lakes), and *developed* sites (on developed sites). Results are shown in Table 3 and Fig. 3-6 below. Note that statistical analyses were not done for the coarse woody debris data.

Table 3: Results of randomization tests comparing undeveloped vs. random sites and random sites vs. developed sites. Significant difference noted by the *p*-values; ns=not significant.

Variable		***Undeveloped vs. Random***	***Random vs. Developed***
Riparian Vegetation	Tree cover	ns	$p < 0.01$
	High shrub cover	ns	$p < 0.001$
	Low shrub cover	$p < 0.05$	ns
	Ground cover	ns	ns
Shoreline Vegetation	Overhanging trees	ns	$p < 0.05$
	Overhanging shrubs	$p < 0.01$	ns
Littoral Macrophytes	Emerg+subm+floating	ns	ns
	Floating leaf	ns	ns
	Ground cover	ns	ns

Riparian and shoreline vegetation: In the riparian zone, both tree and high-shrub cover were lower in developed compared to random sites in developed lakes, but were not different when random sites were compared to undeveloped lake sites (Table 3; Fig. 3). In contrast, low-shrub cover was lower in random sites in developed lakes compared to undeveloped lake sites but there was no difference between random and developed sites. Ground cover showed no pattern. Overhanging vegetation was significantly higher in random sites compared to developed sites for trees. In contrast, overhanging shrubs were more abundant in undeveloped compared to random sites but there was no difference between sites in developed lakes (Fig. 4).

Figure 3: Mean (±std error) of percent coverage of different strata of riparian vegetation in undeveloped sites in undeveloped lakes and in random and developed sites in developed lakes.

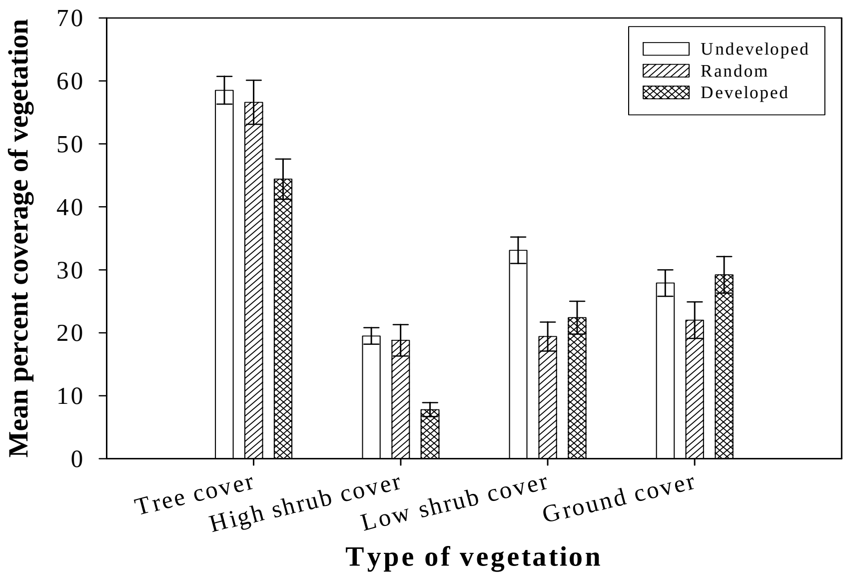
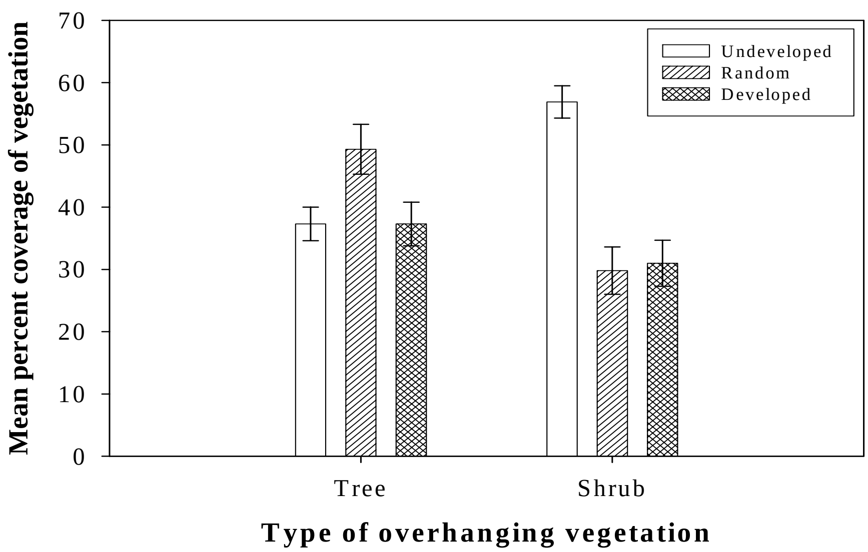
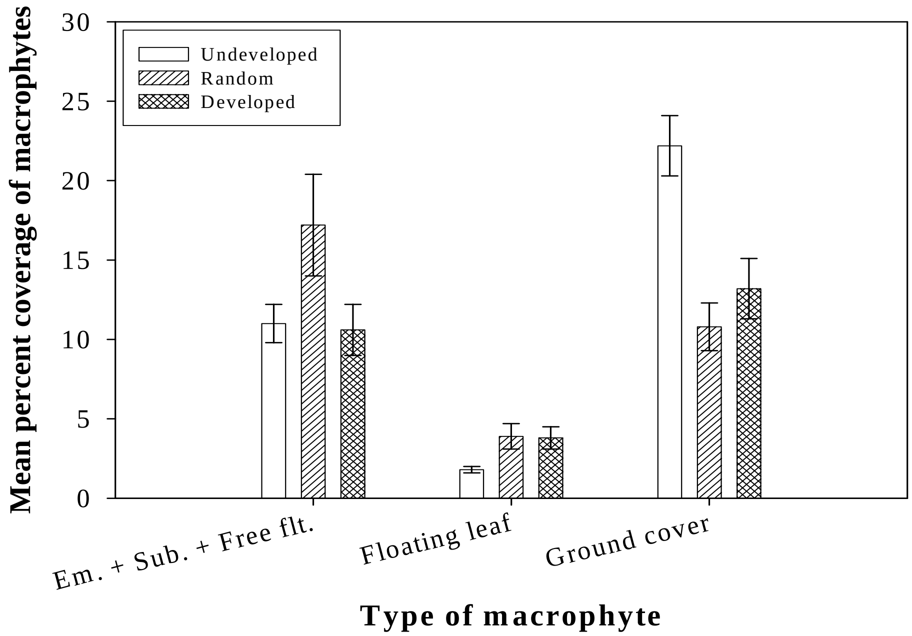


Figure 4: Mean (±std error) of % coverage of overhanging shoreline trees and shrubs in undeveloped sites, and random and developed sites from developed lakes.



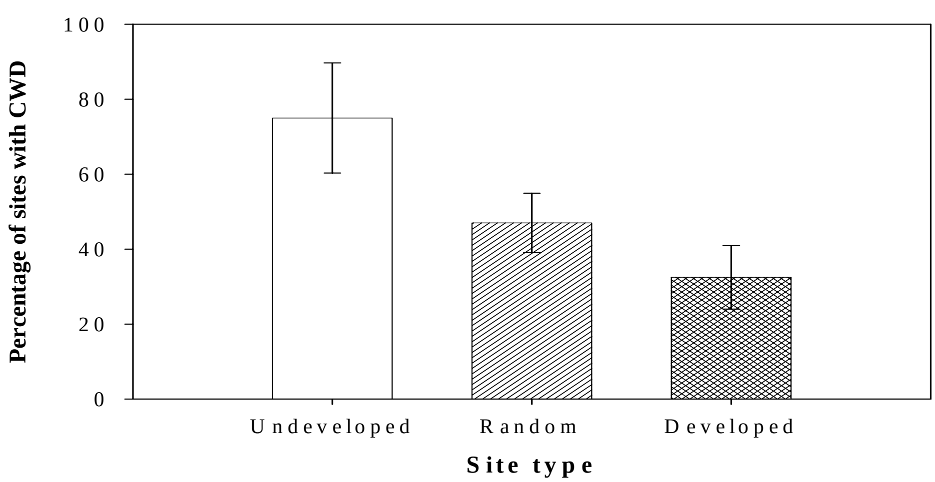
Littoral aquatic vegetation: We did not find any significant patterns in the coverage of littoral macrophytes for any of the functional groups (Table 3; Fig. 5).

Figure 5: Mean (±std error) of macrophyte percent coverage in undeveloped lakes and in randomly chosen and developed sites in developed lakes. The percent coverage by emergent, submergent, and freely floating vegetation were added together for this analysis.



Coarse woody debris. Coarse woody debris (CWD), summarized as the percentage of sites on a lake with coarse woody debris, was more common on undeveloped lakes compared to developed lakes (Fig. 6). Within developed lakes, CWD was more commonly encountered on random sites compared to developed sites. Note that statistical analyses are not yet available for these data.

Figure 6: The percentage of sites with coarse woody debris in undeveloped lakes, random sites on developed lakes, and developed sites on developed lakes. Means (±std error) are based on lake means.



Significance:

Results form the NMS analysis support our hypothesis that variation in habitat complexity is in part defined by physical factors such as fetch and sediment composition. The group of macrophytes (emergent + submergent + freely floating) that provide structure to the littoral zone was found in the highest percent coverage at sites with fine sediments. Fetch and wave action in shallow littoral areas generally remove fine grained sediments (Håkanson 1982; Petticrew and Kalff 1991). The removal of fine grained sediments in areas with high wave action can have an effect on the macrophyte community structure because macrophytes can be physically damaged by waves and conditions may not be as favorable for plant growth (Keddy 1982). Defining these patterns in physical variables is an important step for creating expectations regarding the presence of macrophytes and coarse woody debris in our Maine study lakes.

Based on comparisons of developed and randomly chosen sites in developed lakes, the site-specific effects of shoreline development included fewer trees and high shrubs along the riparian zone and the shore. Surprisingly, low shrubs and overhanging shrubs were lower in randomly chosen sites in developed lakes compared to undeveloped lakes suggesting that the effects of shoreline development were manifest at the whole lake scale, in addition to the direct and mechanical affects of development. An effect of shoreline development on littoral habitat complexity was suggested by the patterns shown by coarse woody debris occurrence, with highest occurrence in undeveloped lakes, followed by random sites then developed sites in developed lakes. We did not find strong evidence for an effect of shoreline development on macrophyte structure. If anything, the data in Fig. 5 suggest that the random sites in developed lakes have the most structure based on the sum of percent coverage by emergent, submerged and freely floating forms. The logistic regressions needed to statistically test patterns of occurrence for both coarse woody debris and macrophytes are in progress.

Our finding that the incidence of coarse woody debris is lower in developed lakes corresponds to conclusions from other studies (Christensen et al. 1996). Our lack of clear-cut results for macrophytes, however, differs from studies that have reported a reduction in macrophytes with shoreline development from recreational use of the littoral zone and physical removal of plants by residents (Radomski and Goeman 2001; Jennings et al. 2003). One possible reason for these differences is the low intensity of development in our downeast Maine lakes. We will further refine our analysis through including a variable from the NMS to account for intra-lake variation related to the natural template.

Summary:

Our research has begun to develop a system for including measures of the natural physical template underlying heterogeneity in the littoral zone into an analysis of the effects of lake shoreline development on habitat complexity. Through this work we can ultimately identify rapid assessment metrics for use by management agencies to asses the impacts of shoreline development. Our results to date suggest both site specific and lake scale effects of shoreline development on riparian vegetation. By refining these and including an analysis of the biotic responses to alterations in habitat complexity we can more fully assess the effects of development initiated prior and after the passage of shoreline regulations.

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This grant supports Kirsten Ness' research for her M.Sc. degree in Ecology and Environmental Science (EES), with a concentration in Water Resources. Matching funds from the University of Maine have provided additional support via a Research Assistantship (2003-2004) from the Maine Agricultural and Forestry Experimental Station (USDA) and a Teaching Assistantship (2004-2005) from the Department of Biological Sciences.

Notable Awards and Achievements

Kirsten Ness won the best oral presentation in the Ecology and Marine Sciences category at the University of Maine Association of Graduate Students Research Exposition, April 2005.

Publications and Presentations

Ness, K., K.E. Webster, R. Bouchard. 2005. What are the effects of shoreline development on lakes in Maine? Oral presentation at the Maine Water Conference, March 2005, Augusta.

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